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OPTICAL AND THERMAL PERFORMANCE ANALYSIS OF SOLAR PARABOLIC CONCENTRATOR

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ABSTRACT

In this work, the effect of reflectivity of the reflector, absorptivity of the absorber, intercept factor and beam solar radiation in the thermal performance of a solar parabolic concentrator (SPC), are investigated. The optical energy input of a solar thermal collector is important, to achieve the maximum thermal performance. Polished aluminium, steel sheets and glass, with low iron content are used as the reflector materials. The absorber coating is black chrome and nickel for the improved heat absorption rate. The reflectivity of the reflector and the absorptivity of the absorber surface are the most influencing parameters, for the optical and thermal performance of SPC. An increase of 0.2 reflectivity or absorptivity, enhances the optical efficiency by 18%. The maximum temperature attainable over the absorber is 650 C, during the outdoor testing, without passing the fluid through the absorber.

***KEYWORDS:** Optical Efficiency, Concentration Ratio, Parabolic Dish, Absorber Coatings, Reflectivity & Absorptivity*

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Original Article

INTRODUCTION

Most of the solar collector thermal output depends primarily on the optical properties like the reflectivity of the reflector, the absorptivity of the receiver surface and focal image size and emissivity of the receiver surface. In the concentrated collectors, the tracking parameters are also responsible for the energy available at the absorber surface. Inhamed et al. [1] assessed the effect of the acceptance angle, effective concentration ratio over optical efficiency and the flux distribution on the receiver surface area, for different concentrator heights. The optical efficiency of 27%, which was three times higher than the circular concentrator profile value of the aspect ratio of 5, acceptance angle ±30, the concentration ratio 20 and the concentrator height 0.4 m. Li et al. [2] used Gaussian and polynomial model, to calculate the system efficiency. The optimal rim angle decreases, when considering the effects of the incidence. Huang et al. [3], conducted the optical analysis of solar concentrators. Huang et al. [4] investigated the optical performance of the Fresnel lens solar collector with azimuth tracking, using ray tracing software SolTRACE. Pavlovic and Stefanovic [5] investigated optical design of SPC, using a ray tracing software TracePro and obtained the maximum value of total solar flux density and average irradiance-solar radiant energy, at the spirally corrugated absorber.

Pavlovic et al. [6] used the mathematical tool, Engineering Equation Solver and simulation tool OptisWorks, to evaluate the parabolic dish with spiral absorber. The energetic performance of working fluids thermic oil, water and air were compared as, the most energy efficient water at low temperature and oil at high temperature operations. The air was observed with maximum exegetic performance than water and oil at low temperature operations. Phase change materials are recently used in the thermal storage systems of solar collectors.

Many researchers have investigated the heat transfer in phase change materials [7 -10]. The temperature distribution on the solar receiver and the utilization of phase change material is, to provide uniform temperature distribution inside the receiver [11-13]. Further, the recent developments in the solar receivers are reviewed by Senthil [14]. Study on selective coating on the solar receiver and effect of integrated storage on SPCusing nitrated salts and sugar alcohols are investigated by several researchers [15-20]. Based on the literature, the optical and thermal performance of parabolic trough and dish collectors are investigated for the past few decades. However, the Scheffler type reflector based solar collectors are not much investigated. In this work, the optical parameters and their effect on optical efficiency and thermal performance, are studied parametrically and verified with the stagnation testing in the outdoor conditions.

MATERIALS AND METHODS

The effect of optical parameters is studied parametrically. The presented study is confined to the testing of the absorber, without working fluid. The maximum attainable absorber temperature is verified experimentally. Highly polished aluminium sheet and solar grade mirror, are considered for the reflector. The black chrome coating is considered for the absorber. The geometric concentration ratio of the SPC, is the ratio of the aperture area of SPC, to the absorber area. The effective concentration ratio is the product of optical efficiency and geometric concentration ratio.

C = Absorber surface area / Collector aperture area (1)

C_{eff}= Optical efficiency x Concentration ratio (2)

The optical efficiency of PDSC, depends on the optical properties of dish reflector material like reflectivity (ρ), intercept factor (γ), the transmittance (τ) and absorptivity (α) of the receiver, expressed as:

$$\eta_{optical} = \rho\ \gamma(\tau\alpha)\cos\theta \tag{3}$$

The actual collector aperture area is inclined downward at an angle of (43.23 ± half of declination angle) degrees due to the lateral part of a paraboloid. Solar declination angle (δ) is calculated using the n^{th} day of the year, starting from January 1, from the following equation,

$$\delta = 23.45\ \frac{\pi}{180}\ sin\left[2\pi\ \frac{(284+n)}{36.25}\right] \tag{4}$$

The aperture area, A_c of the reflector at any day of the year depended on solar declination and expressed as.:$A_c = A_f.\ cos\ (43.23 \pm \delta/2)$ (5)

Where, A_f is the surface area of the reflector (m^2) and δ is the solar declination angle. The positive (+) or negative (-) sign applies to northern and southern hemisphere, respectively [21]. The specifications of parabolic dish collectors are given in Table 1.

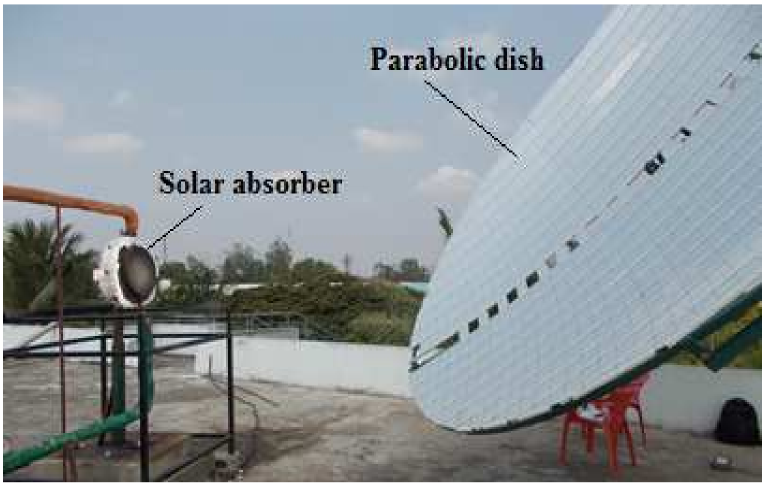

Figure 1: Solar Parabolic Concentrator

Table 1: Specifications of SPC

Item	Specifications
Parabolic dish collector aperture area	16 m^2
Actual Concentration ratio	90 -100
Reflectivity of mirror	0.9
Emissivity of absorber coating	0.2
Absorber surface area	0.126
Focal distance	2.7 m
Material of the absorber	Mild Steel

RESULTS AND DISCUSSIONS

The parametric study of the effect of optical properties, over the optical and thermal performance is carried out for the SPC. Figure 2, shows the variation of concentration ratio over the months, based on the solar declination angle at the test site, for the selected SPC. The variation is observed due to the sun position in each month. The average concentration ratio is 116. The actual concentration ratio is responsible for the maximum receiver surface temperature, in the sunny days.

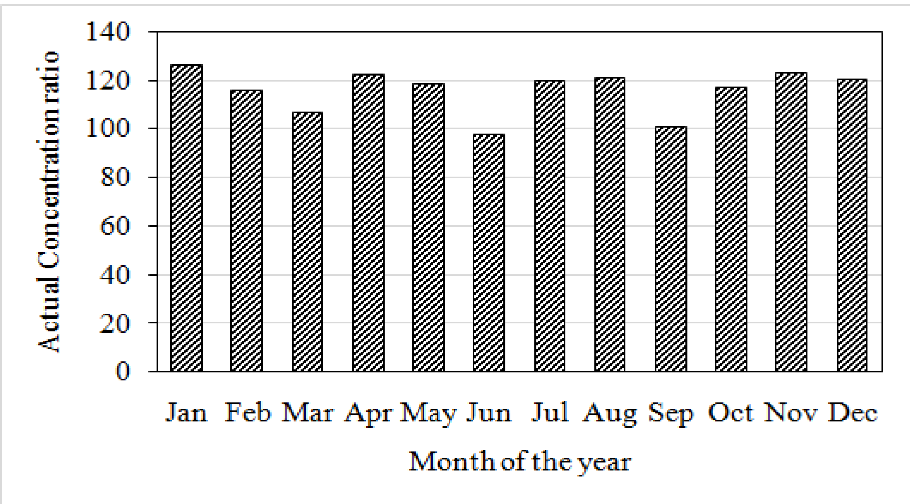

Figure 2: Actual Concentration Ratio Over the Months

From Figure. 3, the optical efficiency increases 17%, while the reflectivity of the dish increases from 0.75 to 0.85, while all other optical properties are maintained constant, if the absorptivity of the receiving surface, increases from 0.7 to

0.9, which increases the optical efficiency by 18%, as shown in Figure. 4. During the parametric study, the variation of other parameters is assumed negligible.

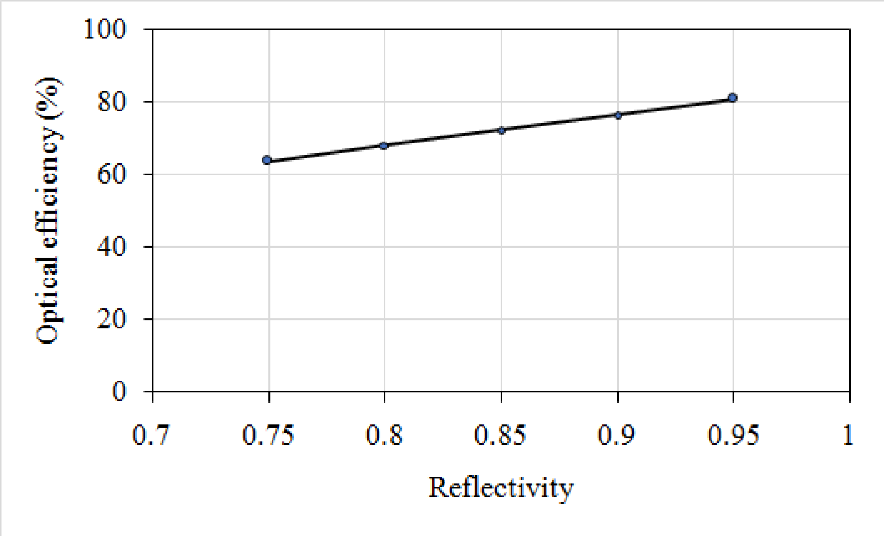

Figure 3: Effect of Reflectivity on Optical Efficiency of SPC

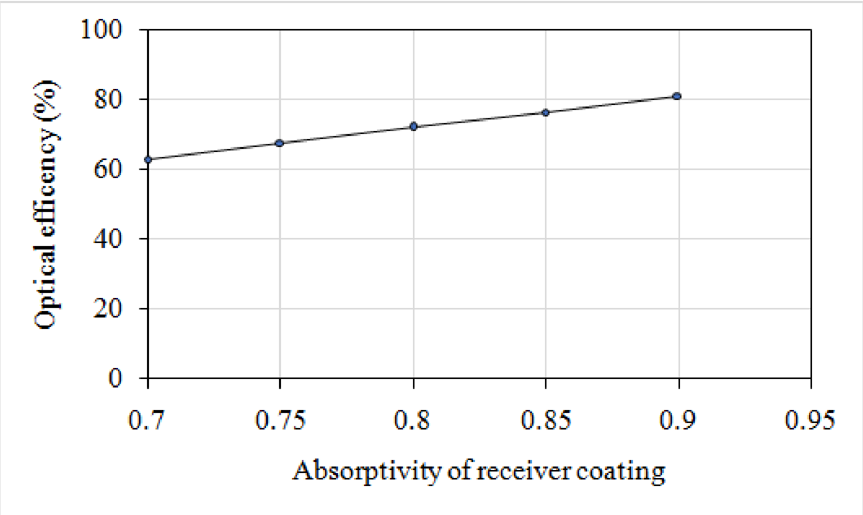

Figure 4: Effect of Absorptivity on Optical Efficiency of SPC

Figure 5, shows the effect of intercept factor on the optical efficiency. The intercept factor is varied from 0.8 to 1.0, the optical efficiency increases by 15.3%. However, the intercept factor is applicable for the absorber, placed over the dish reflector. In the present parabolic dish reflector, the absorber is kept away from the dish, at a fixed focus. The dish reflector is used to track the sun through two-axis and maintained the focus on the fixed absorber. The maximum optical efficiency attainable is 76.5%, based on the optical data of the reflector and absorber coating.

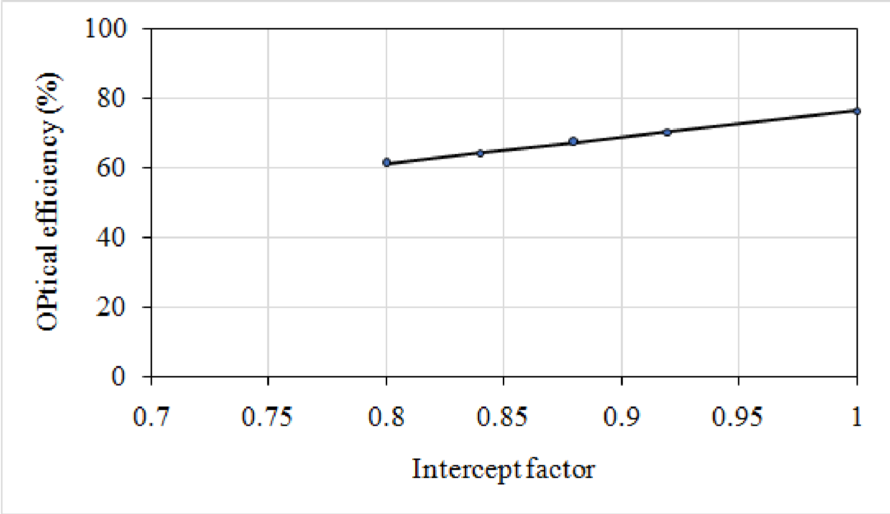

Figure 5: Effect of Intercept Factor on Optical Efficiency of SPC

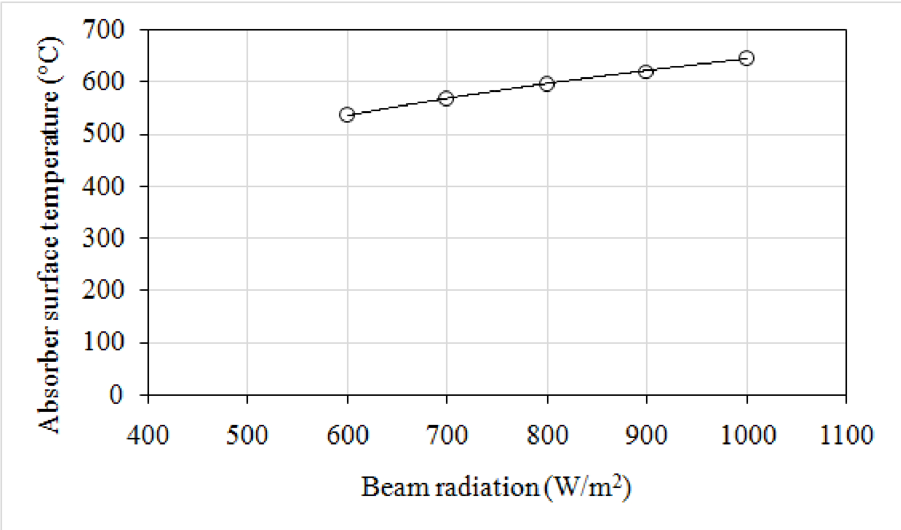

Figure 6: Absorber Surface Temperature, Over the Beam Radiation on SPC

The effect of beam radiation on the absorber surface temperature, is depicted in Figure. 6. The beam radiation of 600 – 1000 W/m^2 result in an absorber temperature of 500 – 650 °C. The available beam radiation in the test site is 550 – 750 W/m^2. The maximum temperature of the absorber is predicted for the absorber, without any working fluid. The fluid may be thermic oil, water and air, based on the application requirements.

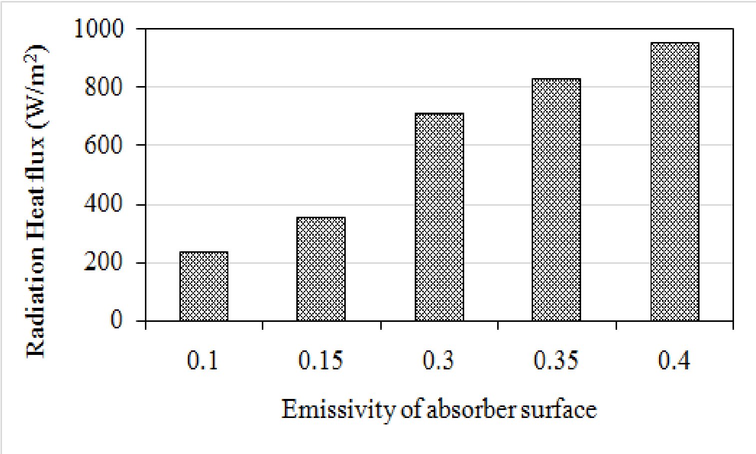

Figure 7: Radiation Heat Flux Over the Emissivity of the Absorber Surface

The radiation heat flux over the emissivity, is shown in Figure.7. The increase in emissivity increases the radiation heat flux. A lower emissivity of less than 0.2 is preferred to the solar concentrators. The emissivity is important for absorber surface, to reduce the radiation loss. The higher absorber surface temperature, leads to the maximum thermal output of the solar thermal system.

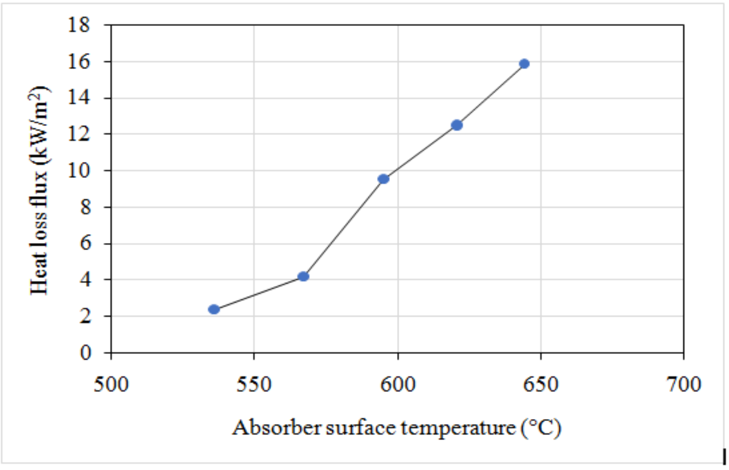

Figure 8: Heat Loss Flux Over the Absorber Surface Temperature

Figure 8, shows the effect of absorber surface temperature, over the radiation heat loss, if 100 °C rise of absorber temperature increases the radiation heat loss by 13.4 kW/m^2. This is applicable to the absorber, without heat gain to the fluid. Receiver surface temperature is susceptible to wind convection heat losses too. However, the convection heat losses are eliminated, by providing a glass cover with the high transmissivity. A glass cover is used to avoid the direct contact of wind, with the hot absorber surface. The maximum temperature achieved on the absorber is 650 °C, at the average beam solar radiation of 750 W/m^2 and this maximum temperature is able to melt thin aluminum sheets. Further, the maximum temperature has been tested experimentally, using the aluminium sheet of 3 mm thickness of the known melting point. The performed outdoor experiments have been observed with molten aluminum. Thus, the maximum temperature is validated experimentally.

CONCLUSIONS

The effect of optical properties and the radiation heat flux, from the solar reflector- absorber system is determined. The reflectivity of the reflector materials and the absorptivity of the absorber, are the most influencing parameters, for the thermal performance of theSPC. An increase of 0.2 reflectivity and absorptivity, resulted in the improvement of 18% optical efficiency. Highly polished aluminium and solar grade mirrors are available with 0.92- 0.98 reflectivity. The maximum temperature achieved on the absorber is 650 °C, at the average beam solar radiation of 750 W/m^2. Such studies are beneficial, to investigate on SPC parametrically.

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